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Status of knowledge on killer whales (*Orcinus orca*) in the Canadian Arctic

État des connaissances sur les épaulards (*Orcinus orca*) dans les eaux canadiennes de l'Arctique

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ABSTRACT

Killer whales or orcas (*Orcinus orca*) are widely distributed throughout the Canadian Arctic, where they likely prey on a large variety of marine mammal species, including those important to the Canadian Inuit. It is therefore important to gain a better understanding of the distribution, ecology, and potential predation impacts of eastern killer whales. Inuit hunters in the Canadian eastern Arctic have reported a recent increase in killer whales sightings, with similar increases reported off Newfoundland and West Greenland. These increases may be due to increased sighting effort, a change in killer whale distributions, population increases, or some combination thereof. This report presents an extensive review on killer whales in Arctic Canada, defined as the Labrador Sea north and west through Nunavut to the Yukon coast. A GIS-database of killer whale sightings has been compiled, which currently holds 485 records (excluding > 200 sightings in the North Atlantic). While there are a number of biases inherent in this database (i.e., inshore versus offshore observer effort, group size determination, predation observations), a summary of the data is nonetheless instructive in cataloguing knowledge on killer whales in the Canadian Arctic.

The majority (87%) of killer whale sightings occurred in the summer (June-September), although scattered records occur throughout the year. Most sightings have been reported in the southwest Greenland and Lancaster Sound regions. Group sizes reported ranged from one to up to over 100 animals, and most sightings (82%) involved more than one killer whale. Median group size was three whales. A total of 122 records included information on predation events, with narwhal (*Monodon monocerus*) the dominant prey species, followed by beluga (*Delphinopterus leucas*) and bowhead (*Balaena mysticetus*) whales. The largest source of killer whale mortality in the Arctic is direct human killing, especially by Greenland Inuit. These harvest levels have increased considerably in recent years and may be unsustainable.

Further study on killer whales in the eastern Canadian Arctic, which is clearly required, is now in the initial stages. A sighting network and photoidentification database are in development, acoustic monitoring has been started, and future plans call for dedicated field work to photograph, record and biopsy sample killer whales. Inuit hunters will be a critical component of Arctic killer whale research. In summer 2007 intensive research will be conducted in Repulse Bay, which has been identified as a focal area for killer whale research, consisting of collection of Inuit traditional knowledge, deployment of two autonomous acoustic recorders, and dedicated field surveys.

RÉSUMÉ

Les épaulards ou orques (*Orcinus orca*) sont largement répartis dans toutes les eaux canadiennes de l'Arctique où ils sont les prédateurs d'une grande diversité de mammifères marins, y compris ceux qui sont importants pour les Inuits. Il importe donc de mieux comprendre la répartition, l'écologie et les effets possibles de la prédation des épaulards de l'Est. Les chasseurs inuits de l'est de l'Arctique canadien ont signalé une récente augmentation des observations d'épaulards; des tendances semblables ont été constatées au large de Terre Neuve et de l'ouest du Groenland. Elles peuvent être attribuables à l'augmentation de l'effort d'observation, à une répartition différente des épaulards, à l'accroissement des populations ou à une combinaison quelconque de ces facteurs. Ce rapport présente un examen exhaustif des épaulards des eaux canadiennes de l'Arctique, définies comme s'étendant de la mer du Labrador au nord et à l'ouest, en passant par le Nunavut jusqu'à la côte du Yukon. Une base de données sur les observations d'épaulards, basée sur le SIG, a été constituée; elle contient actuellement 485 documents (excluant >200 signalements dans l'Atlantique Nord). Bien qu'elle comporte un certain nombre de biais implicites (p. ex. effort d'observation côtier et hauturier, détermination de la taille du groupe, observation d'activités de prédation), le résumé des données est néanmoins instructif pour le catalogage des connaissances sur les épaulards des eaux canadiennes de l'Arctique.

La plupart (87 %) des observations d'épaulards ont eu lieu en été (juin-septembre), malgré quelques observations isolées pendant toute l'année. La plupart ont été faites dans le sud-ouest du Groenland et dans la région du détroit de Lancaster. La taille des groupes signalés varie entre un épaulard et plus d'une centaine, mais une grande partie (82 %) des signalements en concernaient plus d'un. La médiane était de trois épaulards. Au total, 122 signalements incluaient des renseignements sur la prédation, le narval (*Monodon monocerus*) étant la principale espèce proie, suivie du béluga (*Delphinopterus leucas*) et de la baleine boréale (*Balaena mysticetus*). La plus grande source de mortalité chez les épaulards de l'Arctique est l'activité humaine, notamment celle des Inuits du Groenland. Ces taux de chasse ont connu une hausse considérable ces dernières années et pourraient ne pas être durables.

D'autres études sur les épaulards de l'Est du Canada, qui sont clairement nécessaires, en sont au stade préliminaire. Un réseau d'observation et une base de données de photo-identification sont en préparation; la surveillance acoustique a été entreprise et les plans d'avenir prévoient des travaux sur le terrain en vue de photographier, d'enregistrer et de prélever des échantillons biopsiques. Les chasseurs inuits constitueront un élément crucial de la recherche sur l'épaulard de l'Arctique. À l'été 2007, des études seront menées sur le terrain, dans la baie Repulse, qui a été désignée comme point central de la recherche sur l'épaulard. Elles consisteront à recueillir des connaissances traditionnelles inuites, à mettre en place deux sondes acoustiques autonomes et à effectuer des relevés sur le terrain spécialisés.

INTRODUCTION

Killer whales, or orcas (*Orcinus orca*), are the most widely distributed cetacean species on earth, occurring in all oceans. The killer whale is the largest member of the dolphin family (adult males can reach lengths of over 9 m and weigh over 9000 kg) (Ford 2002) and the only cetacean that regularly consumes prey larger than itself. Killer whales in the eastern North Pacific (Alaska-Washington) have been studied extensively (see reviews in Baird 2001; Ford 2002). Killer whales in some other regions are also relatively well known, for example, photoidentification catalogues are in place in Antarctica, Argentina, Iceland, New Zealand and Norway (Lyrholm 1988; Sigurjonsson et al. 1988; Visser 1999; Iñiguez 2001). In contrast, next to nothing is known about killer whales in the Canadian North Atlantic and Arctic regions.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has ranked the eastern Arctic and North Atlantic population(s) of killer whales as "Data Deficient" (Baird 2001). The North Atlantic Marine Mammal Commission (NAMMCO) has determined that there is currently insufficient information to assess status of North Atlantic killer whales (NAMMCO 2004). The only thorough review of North Atlantic killer whales was published in 1988 (Sigurjonsson and Leatherwood 1988, eds.) although research is currently being conducted in the Newfoundland and Labrador region (Lawson and Snow 2007). An updated review on killer whales in the Canadian Arctic (see Figure 1) is clearly warranted, particularly in light of the current (2007) COSEWIC re-evaluation of this species in Canada. Inuit hunters in the Canadian eastern Arctic have reported a recent increase in killer whale sightings. A similar situation has been noted off Newfoundland (Jack Lawson, DFO, pers. comm.) and West Greenland (NAMMCO 2004). These increases may be related to increased sighting effort, a change in killer whale distribution, population increases, or a combination of these factors. This report has been prepared to assist COSEWIC in their re-evaluation of Arctic killer whales and follows a 30 May 2007 meeting, via teleconference, of the DFO National Marine Mammal Review Committee.

Killer whales in other regions can be separated into different ecotypes based on prey species, acoustic behaviour, genetics and morphology. It is not known whether or not Arctic killer whales can be classified into ecotypes such as those in the Pacific Northwest or the Antarctic (Ford et al. 2000; Baird 2001; Pitman and Ensor 2003). Similarly unknown is whether the whales occasionally observed in the Northwest Territories and Yukon are transient animals identified from Alaska. Published accounts of killer whale predation in the Arctic indicate that these animals prey on a wide variety of species in Arctic waters, including bowhead whales (*Balaena mysticetus*), beluga (*Delphinopterus leucas*), narwhal (*Monodon monocerus*) and seals (MacLaren Marex Inc. 1979; Steltner et al. 1984; Campbell et al. 1988; Heide-Jorgensen 1988).

The Department of Fisheries and Oceans Canada (DFO), Central and Arctic Region, has recently initiated a new research project, Orcas in the Canadian Arctic (OCA) (led by S.H. Ferguson), to improve knowledge on killer whales in Arctic regions. The OCA project started in September 2005 and is comprised of a group of volunteers from DFO, the University of Manitoba, Nunavut Tunngavik Incorporated (NTI), the Government of Nunavut (GN), environmental consulting groups, and others. The research goals of OCA are developing a GIS database of past and current killer whale sightings, soliciting future sightings through a community monitoring network, conducting acoustic monitoring, building a photoidentification database, compiling *Inuit Qaujimajatuqangit* (IQ, Inuit Traditional Ecological Knowledge), and collecting samples for genetic and other analyses, all with the aim of improving knowledge of eastern killer whale population dynamics, movement patterns, social structure and predation impacts.

To date most research efforts have concentrated on compiling available information on Arctic killer whales through a comprehensive literature review. This review led to a GIS database of killer whale sightings and associated information including date, group size, and predation observations. A killer whale sighting form (Figure 2) has also been developed and distributed to Hunters and Trappers Associations/Organizations and GN Conservation Officers throughout

Nunavut. A small number of photographs have been collected, all of which were taken opportunistically in areas throughout Nunavut. Some acoustic monitoring has been conducted, and analyses of recordings are ongoing. The objective of the current study is to summarize current knowledge on killer whales in the Canadian Arctic by summarizing the database created by the author. This includes mapping and summarizing distribution patterns and reported predation events, and summarizing available data on ecological factors such as group size, age and sex composition, seasonality, and population dynamics and mortality. Data of the sort used here contain inherent observer biases, including increased effort nearshore (versus offshore), biases in determining group size, and biases in observations of predation events (i.e., predation on large whales is much more visible, and hence more likely to be observed and reported, then predation on seals or fish). Nonetheless, a summary of the database will be instructive in cataloguing the current state of knowledge on Arctic killer whales.

THE DATABASE

The latest version (01 March 2007) of the killer whale sightings database contains 485 records (Arctic regions only, i.e., excluding the North Atlantic) (Figure 3). Most killer whale sightings were collected through an extensive literature review that included peer-reviewed studies (e.g., Steltner et al. 1984; Campbell et al. 1988; Heide-Jorgensen 1988; Reeves and Mitchell 1988a, b; Finley 1990; Pattie and Webber 1992), government documents (e.g., Richard 1998), consulting and NGO reports (e.g., Stepney and Wooley 1975; Ford et al. 1986; Milani 1986), books (e.g., Sergeant 1968) and newspaper articles (e.g., Anon. 2004; Reaney 2004). Additional sighting data were collected through a number of personal communications from DFO staff and other government employees, ecotourism operators, consultants, and northern residents. Several sighting forms (Figure 2) have been returned to DFO by Inuit hunters in Nunavut. Peer-reviewed journal articles, chiefly those published in Sigurjonsson and Leatherwood (1988), provided the majority of reports (395). Most of these records were collected from Reeves and Mitchell (1988b) and Heide-Jorgensen (1988), who provided extensive reviews of killer whales in the Canadian eastern Arctic and West Greenland, respectively. This report is an attempt to update the information contained in those two sources (although the database is deficient in recent records for non-Nunavut regions, particularly West Greenland).

All sightings were assigned to the marine ecoregions defined by DFO (Powles et al. 2004). In total there are 19 ecoregions, including six in the Pacific region, seven in the Atlantic region, and six in the Arctic Region. The Arctic and Atlantic regions were used here where applicable, with some exceptions and modifications. Several Atlantic ecoregions were excluded as they are outside of the administrative boundaries of the Central and Arctic Region (i.e., those in the Maritimes, Quebec and Newfoundland). Scientists in these regions are compiling similar databases (e.g., Lawson and Snow 2007), and funding has been secured to merge these databases under a common database structure (DFO National Science Data Management Committee funding). The Labrador Sea ecoregion was split into northern and southern regions, and only those sightings in the northern region were included here. Whales seen in northern Labrador possibly travel further north and may constitute part of the "Arctic population". The Northern Labrador ecoregion was subdivided into Labrador and Nunavik/Nunavut subregions (i.e., split at the southeastern end of Hudson Strait). The sightings database overlaps with the Newfoundland and Labrador Region (Lawson and Snow 2007) for northern Labrador. However Lawson and Snow (2007) plotted records (n = 205) for the period 1967 to 2007 only, with the majority of these records coming in the last seven years. The few northern Labrador sightings included in this report were all collected from papers in Sigurjonsson and Leatherwood (1988) and there is thus little to no overlap in the sightings plotted by Lawson and Snow (2007). The Hudson Complex ecoregion (Powles et al. 2004) was subdivided into the four ecoregions defined by Stewart and Lockhart (2005). A number of marine mammal stocks are shared between Canada and Greenland, and killer whales may be no exception. Sighting records from Greenland

were therefore included, subdivided into two regions: southwest Greenland (Disko Bay south) and northwest Greenland (Uummannaq District north).

In total 22 Arctic and Atlantic ecoregions were defined, of which six were excluded from this version of the database (Figure 4). The ecoregions, with the number of killer whale records per ecoregion, are shown in Table 1. The southwest Greenland ecoregion contains the most records (148), chiefly from Heide-Jorgensen (1988). The Lancaster Sound ecoregion follows with 80 killer whale reports, followed by the southern Baffin Island region (i.e., the northern half of the northern Labrador ecoregion of Powles et al. 2004). The Hudson Complex, comprised of four regions identified in Table 1 (Hudson Strait, Hudson Bay, Foxe Basin, and eastern Hudson Bay-James Bay), contains a total of 80 records. All other regions contain smaller numbers of sighting reports. The Arctic Basin, Viscount Melville and Queen Maude Gulf ecoregions contain no records.

DATABASE SUMMARY

Distribution of reports through time

Killer whale sighting reports span from 1756 to 2006. Most records from the 1800s and before are from bowhead whaling logbooks (mostly from Reeves and Mitchell 1988a, b). Most records (435) have the year of the sighting. The remaining records have estimates within a couple years, the decade in which the sighting occurred, or qualitative statements such as "recently" or "a long time ago". The number of sighting reports increases almost every decade after the 1900s, rising to a peak in the 1980s (Figure 5). There is then a considerable decline for the 1990s and a subsequent increase after 2000. The large number of records for the 1980s is related to the publication of the special issue of Rit Fiskideildar in 1988 (Sigurjonsson and Leatherwood, eds. 1988). Since these analyses were completed an additional eight killer whale records have been collected; with one from the 1930s, one from the 1970s, one from the 1990s and the remainder from the most recent decade.

Table 2 shows the number of killer whale records per time period (decadal after 1900) for the eight regions with the most sighting reports. Biases inherent in this type of database preclude any inferences regarding population increases over time. However it is apparent that killer whales were historically present in the Davis Strait and Baffin Bay region, with records going back to the 1800s. It is also apparent that killer whales are a relatively recent arrival to the Hudson Bay area. Higdon et al. (2006) and Higdon and Ferguson (2007) showed that increases in killer whale sightings in Hudson Bay are statistically correlated with declining summer sea ice in Hudson Strait (also Higdon and Ferguson in prep.). This suggests that killer whales are extending their range in the eastern Arctic as climate warming occurs, which is also supported by Inuit observations.

There is little available information on abundance or density of killer whales in the Canadian Arctic, and it is unknown if increases in sightings are representative of a growing population. Killer whales have only been recorded once during DFO aerial surveys for Arctic marine mammals, despite considerable effort in surveying beluga, narwhal, bowhead, walrus and ringed seal stocks. In 2004 a group of seven killer whales was observed (and photographed) from a single-engine plane in southwestern Hudson Bay while surveying belugas (Richard 2005). This is the only time killer whales have been recorded on DFO aerial surveys. A group of nine whales was also observed in Admiralty Inlet in 1985 during a helicopter survey for narwhal (L. Dueck, DFO, pers. comm.). Killer whales have also been reported occasionally during aerial surveys conducted by consulting companies (Stepney and Wooley 1975; MacLaren Atlantic Ltd. 1978). Killer whales have also been occasionally observed on Canadian Coast vessels (J. Ferland, pers. comm.; P. Hall, DFO, pers.comm.; T. Janzen, DFO, pers. comm.). Ultimately however, killer whales have been recorded on only a few occasions over thousands of kilometres of aerial and ship-based surveys, suggesting that numbers are too low to make surveys an effective way to measure population size.

Spatial distribution of killer whale sightings

Killer whales have been reported throughout the study area (Figure 3). The lack of sightings around the central Arctic islands may be somewhat related to lack of observer effort. However the presence of multi-year sea ice may preclude killer whale presence and the region does exhibit lower primary productivity and low densities of other marine mammals. Table 1 provides a rough measure of the relative abundance of killer whales in various regions. The West Greenland coast from Disko Bay south and the Lancaster Sound region have the highest numbers of sighting reports. Several areas appear to have somewhat regular occurrences of killer whales, including Pond Inlet/Bylot Island, Lancaster Sound, Admiralty Inlet, Cumberland Sound, western Hudson Bay (particularly the Repulse Bay area), and Disko Bay in Greenland.

Killer whales are rarely reported in the western Canadian Arctic. Byers and Roberts (1995) interviewed hunters and elders in Tuktoyaktuk, Aklavik and Inuvik to collect traditional knowledge on beluga, and only 15% of the hunters interviewed had seen killer whales. The database contains 21 killer whale sighting reports, all in the Beaufort Sea – Amunsden Gulf ecoregion. Most of these reports are from the interviews conducted by Tim Byers. Inuvialuit hunters have observed whales in a number of areas throughout the western Arctic and also have observed predation on belugas (Byers and Roberts 1995; Byers, unpub. data). Inuvialuit reported 2-3 sightings per decade from the 1940s to the 1980s. Most of these interviewees unfortunately did not provide information on the number of whales observed, although one elder did observe 20 killer whales off Baillie Island in the 1940s (Byers and Roberts 1995). Parks Canada provided two reports for the Aklavik area: from 5-8 killer whales were observed in the 1980s, and animals were also observed there in the 1970s (I. McDonald, Parks Canada, pers. comm.) (NOTE: a killer whale sighting form submitted after these analyses were completed reported a sighting of 15 killer whales near Baillie Island in 1976). Most recently a single killer whale was reported several times in the Kendall Island and Beluga Bay area in mid-July 2006 (E. Hiebert, DFO, pers. comm.; J. Sarault, DFO, pers. comm.; also reported via killer whale sighting report).

Killer whales observed in the western Canadian Arctic are likely coming east from northern Alaska, were they are occasionally reported (Lowry et al. 1987; George and Suydam 1998), and not through the central Arctic. However no effort was made to include Alaskan sightings in this database. COSEWIC is assessing the "Eastern Arctic" killer whale population and have not defined a population in the western Arctic. West Greenland records were therefore included, because of the possibility of a shared stock (or stocks) with eastern Canada, while Alaskan records were not.

Seasonality

The majority of records (n = 387) provide the month or season of the sighting. Most provide month of sighting, with 49 records indicating season only (spring, summer, and fall). While sightings have been reported throughout the year (Figure 6), the majority (87%, n = 337) have occurred in the summer (June-September, including 39 records that note 'summer'). Figure 6 indicates an increase in sightings from June to July and peaking in August, with a subsequent decline in September. While several factors may be responsible for this trend, one possibility is that killer whales migrate northwards in the spring along the Labrador coast and into ice-free Arctic regions, as suggested by Sergeant and Fisher (1957). In their comprehensive review, Mitchell and Reeves (1988) concluded that biases in effort precluded any determination of movement or seasonal distribution patterns.

Occurrence in polar regions is thought to be limited by the presence of pack ice in the winter months (Reeves and Mitchell 1988a), although Gill and Thiele (1997) observed killer whales deep in Antarctic sea ice in winter, indicating that not all individuals migrate to lower latitudes from the poles by early winter. Gill and Thiele (1997) attribute the extreme seasonal differences in sightings to a reduction in observers in winter months, which may add to the perception that

these animals migrate. Differences in sea ice (multi-year versus annual) may again result in differences between the two polar regions. There may also be a detection bias, such that whales are easier to see in open water than among ice. To examine latitudinal trends I plotted day of year against latitude for the 245 eastern Arctic sightings with date values and another 129 records from the North Atlantic (chiefly from papers in Sigurjonsson and Leatherwood 1988) (Figure 7). No evidence of large scale northward migration is evident, and sighting locations are scattered throughout the Canadian eastern Arctic and North Atlantic, at a range of latitudes, for each of the summer months. There is a slight peak in the maximum latitude of sightings at ca. day 220 (early August), however at the same time killer whales are also observed at a range of latitudes from ca. 45 to 75 degrees North. One interesting trend in Figure 7 is the apparent lack of sightings near 55 degrees north latitude. This likely represents a lack of observer effort along the Labrador coast (itself a function of a relatively short coastline), which increases the difficulty of interpreting killer whale seasonal migration patterns.

Regularly occurring groups of killer whales have been observed off southern Labrador and northern Newfoundland, and whales inhabit the region throughout the summer months (Lien et al. 1988; Lawson and Snow 2007). Killer whales are capable of long movements (Visser 1999), but the distribution of sightings suggests those observed at high latitudes during summer are different whales than those observed around Newfoundland and Labrador at the same time. Also, Lien et al. (1988) noted ice-entrapments around the Newfoundland coast which suggests that at least some killer whales remain in the area year-round. The wintering locations of the killer whales seen in the Canadian Arctic are completely unknown. Some whales may in fact migrate along the Labrador coast to offshore wintering locations in the North Atlantic, even with the evidence against large scale migrations. Wintering off the coast of Greenland is a further possibility, which is supported by harvests by Greenlanders during the winter months (ACS 2002; George 2002; NAMMCO 2004).

Table 3 summarizes the monthly/seasonal distribution of sightings in six areas with regular and somewhat predictable occurrences of killer whales. Killer whale sightings in the Pond Inlet/Bylot Island area peak in July and August, however whales are present into September and even October. No July sightings in Admiralty Inlet are recorded, and sightings are most prevalent in August. However whales are again present into the fall season. The occurrence of killer whales in Admiralty Inlet in August is one of the more predictable distribution patterns in the Canadian eastern Arctic. The Lancaster Sound area is likely used by the same whales observed near Pond Inlet and in Admiralty Inlet. Whales have been reported here between August and October. Whale sightings in Cumberland Sound also peak in August, with occasional reports in both the spring and fall. In the northwestern Hudson Bay region (i.e., Repulse Bay, Lyon Inlet, Roes Welcome Sound) killer whales have been reported from July to September. Disko Bay differs from all these regions, with killer whale sightings reported throughout the year. The number of reports is still highest during the warmer months, but these data do suggest that at least some whales winter off the West Greenland coast. However the database contains a lack of recent records for West Greenland (with the majority taken from Heide-Jorgensen 1988), so it is unknown if these patterns have changed in recent years.

Residency times and movement patterns

The database provides some limited information on killer whale residency times and movements at certain locations. Reeves and Mitchell (1988b) provide some information regarding Cumberland Sound, mostly from bowhead whaling logbooks. In 1867 "some" killer whales were observed at the mouth of Cumberland Sound daily from August 14 to 18, and again on September 9, 13 and 16. It is not known whether the observation represent the same or different groups of whales. Another 1867 logbook reported killer whales in Cumberland Sound on August 18 and 22 (Reeves and Mitchell 1988b). More recently, in summer 1965 a group of killer whales was observed daily for three weeks in Pangnirtung Fiord (Reeves and Mitchell 1988b). The 1873 logbook of the *Arctic* notes that the whalers chased "shoals" of killer whales in Prince Regent Inlet on August 7 and 8 (Reeves and Mitchell 1988b). Yet another logbook summarized by those

authors indicated that "a good many" killer whales were present near Pond Inlet on July 29 1891, and again on August 1 and 3.

In Admiralty Inlet, a narwhal research team observed 12-15 killer whales on 20 August 2005 (J. Orr, DFO, pers. comm.; Laidre et al. in review). The killer whales were observed attacking narwhal, and had also been observed the previous day by local Inuit hunters. Killer whales remained in the area, in "fairly large numbers", until October (N. Iqalukjuak, pers. comm. in Laidre et al. in review). On 16 August 1985 a group of nine whales were observed along the west side of Admiralty Inlet during a helicopter survey for narwhal (L. Dueck, DFO, pers. comm.). Four days later, on 20 August, a group of nine whales was observed near Pond Inlet (Campbell et al. 1988). It is not known if these sightings represent the same group, however the time frame agrees well with Inuit observations that killer whales take 3-4 days to move between Pond Inlet and Arctic Bay (G. Williams, pers. comm.).

There is also some information regarding movements and residency patterns in Hudson Bay. On 16 July 1990 three killer whales were observed off Coat's Island in Hudson Bay (T. Gaston, pers. comm.; Gaston and Ouellet, 1997). This may be the same group of 3-4 whales reported several weeks later (2 August 1990) near Rankin Inlet (Pattie and Webber, 1992). Killer whales were reported in western Hudson Bay multiple times between July and September of 2006. Five whales were observed and photographed off Marble Island, near Rankin Inlet, for two consecutive days (5-6) in August 2006 (L. Froese, pers. comm.; D. Lee, pers. comm.; J. Todd, pers. comm.). A hunter from Repulse Bay was informed, via short-wave radio, that a group of "nine or so" whales were seen heading north past Rankin Inlet on August 6th. These whales also apparently entered Chesterfield Inlet (L. Putulik, pers. comm.). Groups of five and ca. 9 whales were reported on the same day.

On 10 August 2006 narwhal were in Repulse Bay and staying close to shore, suggesting that killer whales were near by (prey species typically avoid killer whale predation by hugging the shoreline in shallow water, a behaviour well known to Canadian Inuit and known as '*aarlirijuk*' in the South Baffin dialect of Inuktitut, Hay et al. 2000). On 11 August killer whales were observed in the area (L. Putulik, pers. comm.), so it appears as though the whales took 4-5 days to travel between Rankin Inlet and Repulse Bay. On 14 August a number of narwhal were observed west of Repulse Bay in shallow water close to shore (J. Higdon, unpub. obs.). Three days later (17 August) residents of Repulse Bay observed killer whales, and at the time there were several hundred narwhals and several belugas hugging the shoreline in town (J. Kringayark, pers. comm.). Killer whales were also reported there in mid-July and mid-September (J. Kringayark, pers. comm.). This suggests that killer whales remain in the Repulse Bay area for ca. one week at a time, but it is unknown whether multiple groups use the area or if the same one makes repeated visits throughout the summer.

Other 2006 reports for the Hudson Bay region were of a group of seven killer whales observed chasing beluga whales near Rankin Inlet on 29 August (G. Lundie, pers. comm. to E. Chmelnitsky), a single adult male observed near Churchill on 1 September (E. Kublutsiak, pers. comm. via sighting form), and two reports from August of groups of 1-2 and 3-4 whales observed in northern Foxe Basin, north of Igloolik Island near Fury and Hecla Strait (P. Hall, DFO, pers. comm.). The different group size reports for 2006 suggest the likelihood that multiple groups of killer whales are using the Hudson Bay region.

Observed group size

A total of 408 records contained at least qualitative information on the number of killer whales observed. One record from Heide-Jorgensen (1988) indicated 1000 killer whales. This was considered a typographic error and removed from the analysis. For records estimating a range of two whales (i.e., 2-3, 4-5, etc.) the lower value was used. For records that included a wider range (e.g., 8-10, 9-13) the median value was used. Numbers of whales reported ranged from one to over 100 (Figure 8), with most sightings (82%) involving more than one killer whale. The mean

number of whales observed (from 277 records with quantitative data) was 10 (SE 1.21), and the median was 3. Most records (78%) with a quantitative estimate were of groups of 10 or less whales. However there are observations of large numbers, with 15 records indicating over 40 whales. It is likely that reports of large numbers of whales (> 100) refer to multiple groups/pods observed over a short time in the same area.

A Kruskal-Wallis test was used to determine if significant differences existed in killer whale group size between the various regions. This was not significant (at $p < 0.05$), but was nearly so ($df = 12$, $H = 20.54$, $p = 0.057$, adjusted for ties). Table 4, which summarizes group size data for the most important ecoregions, does show one interesting trend. Group sizes, while not significantly different, are generally larger in the Davis Strait-Baffin Bay and northwest Greenland ecoregions.

Any discussion on association of individual killer whales into "pods" or "groups", and associations between different groups/pods, must be framed within a discussion of how these terms are defined. A "pod" is defined as a set of individuals that associate with one another at least 50% of the time (Bigg et al. 1990). Baird and Dill (1995, 1996) defined "group" as all whales acting together in a coordinated manner during an observation period. Baird and Whitehead (2000) examined social organization among mammal-eating killer whales and concluded that pod designation for transients should only be made for animals seen on multiple occasions both within and between years. The observations in this dataset therefore provide no data on pod size, but do provide information on observed group size. Of 277 records with quantitative estimate of the number of whales, 68% and 84% are ≤ 7 and ≤ 15 animals, respectively.

Group sizes and social structure are considerably different between resident and transient whales in the Pacific. In an eight year study transient group sizes ranged from 1 to 15 individuals, with pod sizes of 1-4 individuals (Baird and Dill 1996). For fish-eating residents, stable pods of individuals along matrilines are large, ranging from 3 to 50 individuals and averaging 12 (Bigg et al. 1987, 1990). Transient killer whale pods appear to be generally comprised of a single matriline with one or two generations, and sometimes includes an adult male which may be a first-born male offspring (Baird and Whitehead 2000; Baird and Dill 1995). Resident pods can contain from 1 to 11 matrilines, each averaging 3-4 individuals and including up to four generations (Bigg et al. 1990). Transient killer whales in Alaska typically travel in small but fluid groups of 1-7 (Matkin et al. 1999). While foraging, distances between mammal-eating individuals in the Pacific can range from less than one body length to over a kilometer (Baird and Dill 1995), so it is therefore highly likely that not all whales were counted in some sightings. For instance, Steltner et al. (1984) described a narwhal predation event near Pond Inlet. The authors observed 30-40 whales from a boat, while shore-based observers observed only two.

In a comprehensive review Baird (2001) stated the largest reported group of killer whales in eastern and Arctic Canada in the last 20 years appeared to be 22 individuals (from Finley 1990). There are accounts of larger groups in the database, however they have not been observed and documented by scientists. Really large estimates (> 50) likely include congregations of different groups near high concentrations of prey. Dedicated observations will be required to determine group structure in these large associations.

Mammal-eating killer whales hunt in a coordinated fashion and share prey after successful kills (Baird and Dill 1995; Hoelzel 1991). Individual whales from different pods interact frequently (Baird and Whitehead 2000) and multipod associations of transients are regularly observed (Baird 1994). These associations are not random, as pods preferably associate with others with similar foraging specializations (Baird and Dill 1995). Sightings of large numbers of whales (over 40) may include several different groups foraging in a close proximity (for example, the ca. 100 killer whales observed near Pangnirtung, Nunavut in 1994, Hay et al. 2000). Mammal-eating killer whales in Argentina concentrate their hunting where the capture rate is greatest, and pods selectivity attack the prey for which they have the highest capture rate (Hoelzel 1991). It is quite possible that certain groups of killer whales specialize on certain prey items in the Arctic, and thus associate with certain other pods, in predictable locations. Another possibility, that again

requires further study, is that some large groups represent stable pods of fish-eating whales (Bigg et al. 1997, 1990).

Group composition

Information on sex and/or age composition of groups was included in 36 records. Four of these were sightings of single whales (three single adult males, one single female), and six were sightings of two whales – three records of two "large" whales, and three records of an adult male with an adult female or juvenile male. Records of four to nine whales generally indicated one or two adult males present. Six records were of 10 to 15 whales, each containing one, two or three adult males (two records each). Three records of 20+ whales simply described a mix of large and small whales or some large animals with dorsal fins > 1 m (i.e., adult males) but did not estimate numbers. Records of 10 or more whales generally indicated that, in addition to 1-3 adult males, groups were comprised of a mix of "medium" and "small" whales, likely females and immature whales ("medium") and young calves ("small"), with more "medium" than "small" whales. While these data are limited, they suggest that groups of < 10 whales generally contain one or two adult males while larger groups contain two or three adult males.

Predation events

Both Inuit and scientific knowledge (Mitchell and Reeves 1982; Steltner et al. 1984; Campbell et al. 1988; Finley 1990; Stewart et al. 1994; Hay et al. 2000; Laidre et al. in review;) have shown that killer whales prey on a variety of other Arctic marine mammal species. A total of 122 records included notes of attempted or successful predation attempts. Several included multiple prey species, for a total of 132 recorded predation events (Figure 8). Killer whales in Canadian Arctic have been observed preying on a large variety of marine mammals in addition to fish. Narwhal was the most recorded prey species (n = 43) followed by beluga (n = 23) and bowhead (n = 20) whales. There were 22 reported predation events on seals, plus one reported predation attempt on Atlantic walrus (*Odobenus rosmarus rosmarus*). Additional cetacean prey species include northern pilot whales (*Globicephala melas*) and other large mysticetes (fin, *Balaenoptera physalus*; minke, *B. acutorostrata*; and humpback whales, *Megaptera novaeangliae*) (Figure 9). Killer whales off southern Labrador have also been observed preying on seabirds (Lawson and Snow 2007). Observer biases preclude any rigorous conclusions regarding the distribution and intensity of killer whale predation, yet it does appear that narwhal may be a choice prey for some groups of killer whales in the eastern Arctic.

Recorded predation events for narwhal were widely distributed across the study area (Figure 10) but were concentrated in Repulse Bay, Pond Inlet, Admiralty Inlet and north Greenland. Inuit in Pond Inlet and Arctic Bay have extensive knowledge of the relationship between killer whales, narwhals and sea ice (Brody 1976). In the spring, killer whales follow narwhals through Pond Inlet and along Eclipse Sound and Navy Board Inlet, and the narwhal migrate through cracks and leads and into Admiralty Inlet to avoid predation. Killer whales do not enter the fiord until the ice has cleared; at which time the narwhal must use shallow water to avoid killer whales (see photographs in Laidre et al. in review). In the fall, when new ice begins to form, both species depart the area. Killer whales leave first, and narwhal delay their departure until killer whales have left, sometimes waiting too late and becoming trapped in the new ice (Brody 1976). Beluga predation has been recorded throughout the study area (Figure 10), including the Beaufort Sea (not plotted). Most reported beluga predation events have occurred in Hudson Bay, Cumberland Sound, and the Disko Bay area of West Greenland. Bowhead whale predation (Figure 10) has been reported in northwest Hudson Bay, Foxe Basin, Hudson Strait, throughout Baffin Bay, Lancaster Sound and Disko Bay. Predation on all three cetacean species has been recorded in the Hudson Bay region.

Stewart et al. (1994) collected local knowledge on beluga and narwhal from four Arctic communities, including information on predation. Hunters in Grise Fiord had seen evidence of killer whale attacks on beluga, but no actual attacks (five hunters interviewed). None of the three

hunters interviewed about narwhal had seen evidence of killer whales attacks. In Arctic Bay one Inuit hunter observed a killer whale attacking a beluga, and the belugas was killed "when it was almost on shore" (Stewart et al. 1994: 15). Another hunter had observed a beluga with scars from a killer whale attack. Inuit in Arctic Bay provided more information on narwhal predation. One hunter reported seeing killer whales attacking a narwhal in August. Another hunter had seen a narwhal killed by a killer whale, in which they ate the meat and fat but left the skin. Killer whales were also reported to have "smashed" a smaller narwhal (Stewart et al. 1994: 34). Hunters in Arctic Bay also reported seeing scars on narwhal from unsuccessful killer whale attacks. None of the interviewed hunters in Foxe Basin had witnessed attacks on belugas, but they had seen evidence of such attacks (i.e., scars and rake marks on beluga whales). The hunters had also not seen attacks on narwhal or evidence of unsuccessful attacks (Stewart et al. 1994).

Predation on seals (Figure 10) has also been recorded throughout the study region, particularly in the Davis Strait area. There is only one record of attempted predation on Atlantic walrus. Winge (1902, in Heide-Jorgensen 1988) reported that a pod of killer whales were chasing a walrus, which hit one of the whales with its tusks, in West Greenland (year not given). Wilkinson (1970) stated that walrus was a prey item of killer whales, especially the calves, but I have seen no other evidence to support this assertion. Indeed, Inuit traditional knowledge suggests otherwise. Degerbol and Freuchen (1935) reported that the killer whale did not enter Hudson Bay, and local Inuit suggested that they were excluded from the bay by the presence of walrus in Hudson Strait. However Degerbol and Freuchen (1935) suggested that the presence of summer ice in Hudson Strait was likely a determining factor, and recent research supports this (Higdon et al. 2006; Higdon and Ferguson 2007). Nonetheless, Inuit knowledge throughout Nunavut asserts that killer whales fear and avoid walrus, and this knowledge has been used by Inuit hunters when in the presence of killer whales. Inuit in Repulse Bay noted that in historic times harpoons were made of walrus tusk, and one could put the tusk in the water to drive killer whales away (R. Stewart, DFO, pers. comm.; H. Cleator, unpublished notes from meeting with Repulse Bay community, 11 January 2006). Similar stories are told in north Baffin, where hunters use two different devices to "fend off" killer whales (Brody 1976). A white enamel coffee was lowered over the side of the boat, into the water. The killer whales see the flash of white and move away because they think it is the tusk of a walrus. Another trick was to lower a paddle or oar into the water and then bellow with the voice of a walrus directly onto the part of the paddle sticking out of the water. The paddle acts as a resonator and transmits the sound underwater. Inuit report that this method could be used by a lone hunter in his kayak to "protect himself…from the attention of killer whales" (Brody 1976: 212).

Whether or not eastern killer whales are segregated into "transient" marine mammal-eating and "resident" fish-eating ecotypes is presently not known. The available data provides observations of predation on both marine mammals and fish, although marine mammal predation events dominate. The two reports of Arctic killer whales eating fish both come from Disko Bay, Greenland. Heide-Jorgensen (1988) includes a 1961 record of Greenland hunters killing 22 (including struck and lost) of an estimated 30-40 killer whales. The stomach contents of the two landed whales included beluga whale, seal (species not given) and fish (species again not given). While certainly not conclusive proof, this evidence may suggest greater plasticity in prey selection in these killer whales. In February 2003 killer whales were killed in Disko Bay, and the stomach contents of those landed included only lumpsucker fish (*Cyclopterus lumpus*) (Laidre et al. in review). Degerbøl and Freuchen (1935) noted that killer whales in Davis Strait also prey on Greenland halibut (*Reinhardtius hippoglossoides*), and Vibe (1980a, in Jensen and Christensen 2003) noted that Greenland killer whales prey on cephalopods to "a large degree". These results suggest that at least some Arctic killer whales prey on fish, but it is unknown if they prey exclusively on these species. Killer whales have been reported eating fish off eastern Newfoundland (Steiner et al. 1979) and also scavenging around longline fishing vessels off northern Newfoundland, coastal Labrador and southern Davis Strait (Sergeant and Fisher 1957; Mitchell and Reeves 1988).

Harbour seals (*Phoca vitulina*) are the most commonly reported prey item for mammal-eating killer whales throughout the northern hemisphere (Jefferson et al. 1991). Baird and Dill (1996) determined that the energy maximizing group size for transient killer whales that hunt harbour seals was three individuals. Groups of three whales had the highest daily energy intake values, and this was also the most frequently observed group size (Baird and Dill 1995). Three was also the median number of whales observed in this study. Killer whales in the Arctic prey on all the different seal species, but the database does show a preference for whales (versus seals) as prey species. If this is the case, optimum group size is likely larger than three whales. However this apparent preference for whales may be due to significant observer biases, as predation on large whales (or even smaller whales like narwhal) is likely much more visible than predation on small pinnipeds. Dedicated observations will be necessary for unbiased estimates of prey selection and predation impact. Another possible source of predation information is analysis of stomach contents (e.g., Heise et al. 2003) of stranded and harvested whales. Available stomach content data include the results discussed above for West Greenland, in addition to a report of ringed seal claws in a stomach in Cumberland Sound (MacLaren Marex Inc. 1979).

Many of the accounts that note predation either provide no information on the number of killer whales present or give a qualitative description only. Accounts of beluga predation indicate attempts by single whales, pairs, and groups ranging from 2-3 animals to 7-10 and up to 30-40 animals (Heide-Jorgensen 1988; Reeves and Mitchell, 1988b). A total of 17 narwhal predation records include estimates of the number of killer whales involved. Two reports involved single killer whales, with four involving from 3-9 whales, eight records of ten to 15, and three reports of large numbers (20-35 whales) (Heide-Jorgensen 1988; Reeves and Mitchell, 1988b). Several published accounts (Steltner et al. 1984; Ford et al. 1986; Campbell et al. 1988) describe predation on narwhal in the vicinity of Pond Inlet. These events involved killer whale groups of 9-10 and 30 or more animals, and occurred in mid to late August, a time when large numbers of narwhal regularly occur in these regions. *Inuit Quajimajatuqangit* provides an interesting account of the cooperative behaviour killer whales exhibit when hunting narwhals. A large killer whale can seize a narwhal from the side and hold it out of the water. The smaller killer whales then swim alongside the whale that made the kill and feed on the narwhal (Brody 1976). Both reports of attempted predation on pilot whales involved a single killer whale (Heide Jorgensen 1988). Reports of predation on seals have involved single killer whales, small groups ranging from two to six, and larger groups of 15-20 whales (Degerbøl and Freuchen 1935; Heide-Jorgensen, 1988; Reeves and Mitchell, 1988b). Seals avoid killer whales by hiding on shore or crowding together on ice pans. When seals are on ice pans, Inuit report that killer whales will surround the pan while one whale pushes up underneath the pan to break it apart and force the seals back into the water (Brody 1976).

The majority of bowhead predation accounts provide no estimate of killer whale numbers. One Inuit account (Hay et al. 2000) described two killer whales killing a bowhead by suffocation (a method described for various large whale species, reviewed by Ford et al. 2005). Another Inuit account in the same source suggested that as many as 100 killer whales were in the vicinity of Pangnirtung, Nunavut in September 1994 and at least one bowhead was killed. Five killer whales were observed attacking a bowhead in Frobisher Bay (Reeves and Mitchell, 1988b). Inuit in Repulse Bay report seeing "bowhead crumbs" floating on the water (R. Stewart, DFO, pers. comm.), and local residents there have suggested that killer whales kill at least five bowhead whales per year in the vicinity (H. Cleator, unpub. notes from meeting with Repulse Bay community, 11 January 2006). Finley (1990) reported two observations of killer whales attacking bowheads in Isabella Bay. In one instance four killer whales (two large, two small) were involved, and the second event involved ca. 22 killer whales in subgroups of 2-6 (but only four killer whales were involved in the actual attack). Fin whales attacks have involved groups ranging from two whales to 8-10 (Heide-Jorgensen 1988; Reeves and Mitchell, 1988b), and reports of minke whale predation in Davis Strait have involved single killer whales, pairs, small groups (ca. 6), and large groups of 40-50 whales (Heide Jorgensen 1988). The available data suggest that a small number of killer whales are capable of successfully killing large whales (Finley 1990; Hay et al. 2000; Heide-Jorgensen 1988; Mitchell and Reeves 1982; Wenzel and Sears 1988).

Sea ice conditions likely influence the spatiotemporal distribution of killer whale predation. Killer whales are considered to generally avoid heavy ice conditions. For example, Inuit hunters in Repulse Bay reported that more killer whales than usual were in the area in 2005 because the ice was late forming (H. Cleator, unpub. notes from meeting with Repulse Bay community, 11 January 2006). However there are also reports of killer whales hunting along ice edges and leads. In the mid-1800s a whaling logbook described a "school of "swordfish" patrolling the floe edge in Lancaster Sound; the whales were supposedly chasing bowheads in cracks in the ice (Reeves and Mitchell 1988b). Killer whales also hunt narwhal along the ice edge in Greenland (Rosing 1999). Locations of satellite-tagged bowhead whales suggest that they adjust their distribution based on ice conditions (L. Dueck, DFO, pers. comm.), and this may be related to killer whale avoidance. Declining sea ice appears to be allowing killer whales to both extend their range and stay longer in Arctic regions (Higdon et al. 2006; Higdon and Ferguson 2007), which will increase predation on other marine mammals.

Killer whale mortality

The database contains some information on killer whale mortality, and additional data are available in a number of published sources. Both ice entrapments and strandings have been reported, but the most significant source of killer whale mortality in the Arctic is direct killing by Inuit hunters. An important component of the upcoming COSEWIC status update will be a summary of known threats and mortality for eastern Canadian killer whales. This section contains a brief summary of known killer whale mortality in eastern Canada and West Greenland.

Few killer whale strandings have been reported in the eastern Arctic. In 1947 a single killer whale was found in Fury and Hecla Strait after it drifted to shore dead, and another was found dead on shore near in Nunavik (eastern Hudson Bay) in 1977 (Reeves and Mitchell 1988b). More recently, an Inuit hunter reported a single dead killer whale (floating) ca. 85 miles north of Churchill, Manitoba in summer 2003 (W. Bernhardt, pers. comm.). Killer whale strandings have also been periodically reported in the North Atlantic (e.g., Dearden 1958; Lucas and Hooker 2000; Mitchell and Reeves 1988). Several reports of Arctic killer whales being trapped in saltwater lakes are also available. In September 1977 14 whales became trapped in a saltwater lake at the head of Cumberland Sound, and all were eventually killed by local Inuit (Mitchell and Reeves 1988; Reeves and Mitchell 1988b). Sometime around 1995 a group of killer whales chased beluga into Chesterfield Inlet. One individual of 2.5-3 m (i.e., a calf) got trapped and was reportedly killed by Inuit (M. Campbell, pers. comm. to M. Chambellant), although this report has not been confirmed.

Ice also represents a source of killer whale mortality. In southwest Greenland in 1940 killer whales were observed throughout the winter, including at a "savssat" (ice entrapment) (Heide-Jorgensen 1988). At least one ice entrapment also occurred in Foxe Basin in the 1950s. Reeves and Mitchell (1988b) reported that two whales, a female and young, were trapped in ice and killed by Inuit hunters in late December 1956. However an Inuit elder reported that in fall 1959, 12 killer whales were trapped in developing ice. Two were captured by Inuit but it was suspected that all the animals died in the end (H. Cleator, unpub. notes from community meeting at Hall Beach, January 12, 2006). It is likely that these two reports refer to the same incident.

Rosing (1999) provides an interesting account from Greenland of killer whale mortality caused by a narwhal. In December 1924 a number of killer whales were killing narwhal amongst ice floes, and one was observed jumping up through the ice, out of the water, with a narwhal on its side with its tusk penetrating to the root straight through the killer whale. The two whales disappeared into the water and were not seen again (Rosing 1999). This is likely an extremely rare source of killer whale mortality.

The largest single source of killer whale mortality is direct killing. Small numbers of killer whales were landed in eastern Canada by commercial whalers before 1972 (Mitchell and Reeves 1988;

Reeves and Mitchell 1988a). However whalers also killed whales both for target practice and to reduce perceived competition for other whales, so harvest statistics underestimate the total kill. Norwegian whalers took a minimum of 45 killer whales off the Labrador coast between 1968 and 1972 (Øien 1988). Bowhead whalers in the eastern Arctic also occasionally attempted to take killer whales but were largely unsuccessful (Reeves and Mitchell 1988b). Hunters in West Greenland reported that killer whales were less common in the 1980s than they were during 1930-1970 (Heide-Jorgensen 1988). This decline may have been related to commercial whaling which ended in 1972.

Canada banned commercial whaling in 1972, and currently the only whaling allowed is for Aboriginal subsistence. Canada's policy on Aboriginal whaling is based on the importance of whales as food for some Aboriginal communities and the fact that whales, and whaling, are an important part of their culture. Aboriginal rights to harvest wildlife are recognized in the Canadian Constitution through land claims and in the Supreme Court decision on the *Sparrow* case. The Canadian Marine Mammal Regulations of the Fisheries Act provide Aboriginals with the right to harvest cetaceans for food, social or ceremonial purposes. Killer whales have also been harvested by Inuit in Canada and West Greenland. In some instances Inuit have killed whales that have become trapped in ice or saltwater lakes (see above), so different sources of mortality are related.

In Nunavut there is no quota for killer whales. The Nunavut Land Claims Agreement (NLCA) states (NLCA 5.6.1) that whenever a total allowable harvest has not been established by the Nunavut Wildlife Management Board, an Inuk has the right to harvest that stock or population up to the full level of his or her economic, social, and cultural needs. However killer whales, which are generally not eaten by Nunavummiut, are not harvested with any regularity and only a small number of harvests have been reported.

There are four known reports of Inuit harvesting killer whales in Cumberland Sound, including the report above of 14 whales killed. Reeves and Mitchell (1988b) also reported that four whales were killed in summer 1969. Two other reports of direct killing in Cumberland Sound have not been confirmed. Killer whales reportedly were chasing beluga close to Clearwater Fiord, and 12 were killed by Inuit from Pangnirtung (R. Richard, DFO, pers. comm.). This apparently occurred in 1981 but may represent confusion with the 1977 record discussed above. A group of 5-6 whales was reportedly killed in the same area "recently" (V. Sahanatien, pers. comm. to M. Chambellant), although this report is third-hand and once again unconfirmed. There is one (unconfirmed) report of Inuit in Foxe Basin harvesting killer whales in addition to the ice entrapment(s) discussed above: in 1967 six whales were harvested (B. Parker, pers. comm.). Baker Lake Inuit also killed a large whale in August 1978 (Reeves and Mitchell, 1988b), and this report is confirmed, unlike the Chesterfield Inlet report discussed above. Another unconfirmed report indicated that Inuit in Arviat were hunting killer whales sometime in the 1980s (S. Stinson pers. comm. to C. Pomerleau). The number of whales killed, if any, was not reported. The available information suggests that killer whales are only periodically harvested by Canadian Inuit, and only in small numbers. Many Inuit hunters in eastern Canada fear killer whales and therefore avoid them.

Heide-Jorgensen (1988) summarized the known harvest mortality of killer whales in West Greenland up to 1987. A bounty was introduced in 1960 in response to complaints from hunters and fishers, but less than 10 whales were submitted for payment between 1960 and 1975, when the bounty was suspended. Between the 1950s and 1980s then official catch statistics underestimated harvests because not all catches were reported and the lists did not include whales struck and lost (Heide-Jorgensen 1988). The total official catch from 1960-1984 was 22 killer whales, or less than one whale per year (Heide-Jorgensen 1988). Once unreported kills and struck and lost whales are included, this rose to 70 whales between 1960 and 1986, with another five killed in the 1950s (Heide-Jorgensen 1988).

In Greenland today killer whales are legal game, with no quota, that may be taken year-round by all licensed hunters. Hunters take whales using small skiffs and harpoon cannon-equipped minke whaling vessels. Hunters report catches in a booklet known as Piniarneq, which also functions as an official hunting license (NAMMCO 1997). The Piniarneq database was established in 1993, and killer whales were included starting in 1996. Reporting is obligatory and hunters must fill out monthly harvest reports in order to renew their hunting permit; however there is no control or verification system for species not regulated by quotas (F. Ugarte, GINR, pers. comm.). The 2005 and 2006 Piniarneq reports provide official (i.e., hunter-reported) harvest data for 1998 to September 2004 (Piniarneq 2005, 2006), with 153 killer whale landings (average 22 per year).

However there is evidence of significant over-reporting: multiple hunters may report the same cooperative harvest (M.P. Heide-Jørgenssen, GIRN, pers. comm., P. Simon, DFO, pers. comm.), and hunters also sometimes check off the wrong species in the table (F. Ugarte, GINR, pers. comm.). Staff at the Greenland Institute of Natural Resources (GINR) recently contacted all hunters who reported killer whale harvests after 1996. After validation, from 1996 to September 2006, 59 killer whale catches have been reported (55 in West Greenland) (F. Ugarte, GINR, pers. comm.). In recent years (since 1996) the West Greenland harvest has varied from 1-21 whales per year, with no whales harvested in 2006 (till September). Harvests were unusually high (21) in 2002 (see below), in all other years the harvest reached a maximum of six whales. This is a significant reduction from the harvests reported in the official, but unverified, statistics. If reported catches are limited to landed whales only, and struck and lost whales are still not reported (*c.f.* Heide-Jorgensen 1988), the possibility of underestimating total removals still exists. Between December 2001 and February 2002 an unusually large number of killer whales were sighted in repeated occasions in the southern part of Disko Bay (F. Ugarte, GINR, pers. comm.). Hunters from several different communities took whales during that period, and 20 catches were reported in the verified harvest series. However, an interview made shortly after suggested that there may have been closer to 40 animals caught during that period (F. Ugarte, GINR, pers. comm.). Outside sources (ACS 2002; George 2002) also reported a total kill of 40 whales.

In summary, known harvests in the eastern Canadian Arctic are low, totalling 21 whales since the 1950s (Table 5). Unconfirmed kills make up the majority of Nunavut harvesting reports; if these unconfirmed kills are added the total harvest becomes 55-56 whales, still less than one whale per year on average. Verified harvests in West Greenland are higher; where a minimum of 130 killer whale shave been taken since the 1950s (note no data for 1987-1995). Harvests are relatively low, however the impact on killer whale population size and dynamics, and social structure, is completely unknown. Baseline data on killer whale abundance is unavailable and clearly required.

It is unknown as to whether the recent slight increase in West Greenland harvest represents an increase in effort or a population increase (or both). Both Mitchell and Reeves (1988) and Lien et al. (1988) suggested that killer whales in eastern Canada were uncommon and numerically few. Lien et al. (1988) suggested that the shooting of killer whales that gathered around whaling ships to feed on captured baleen whales may have significantly decreased populations. Commercial whaling in Canada ceased in 1972, and the recent increases in harvests may be due to numerical increases following large past population declines. Regardless of the reasons for such an increase in killer whale landings, it is completely unknown whether or not this harvest level is sustainable, as there are no population estimates for killer whales in this region. Even occasional shooting could limit population growth because of low potential population growth rates. Baird (2001) suggested that the impact of killer whale harvests in Greenland on Canadian populations should be investigated. With these increasing harvest levels this is an even greater priority today, and it is critical to determine whether such a harvest level is sustainable.

Contaminants likely pose another threat to killer whales in the eastern Canadian Arctic. In the Pacific, killer whales are among the most heavily contaminated marine mammals on earth (Ross 2006). Killer whales are long-lived upper trophic level predators, and a "weight-of-evidence" approach (*c.f.* Ross 2000, 2006) could be used to estimate the potential risk that contaminants

may pose to Arctic killer whales. A number of recent studies (e.g., Muir et al. 1999, 2000; Hoekstra et al. 2003; Braune et al. 2005; Fisk et al. 2005; Hickie et al. 2005) have examined contaminants in the Canadian Arctic, and these studies could be used in conjunction with studies on pinnipeds (summarized by Ross 2000, 2006) to generalize about potential contaminant effects on killer whales. A thorough analysis of contaminant levels in Arctic killer whales will require analyses of biopsy samples from free-ranging and/or dead animals. This work is now in the initial stages but no biopsy samples have been collected to date.

OTHER OCA RESEARCH ACTIVITIES

To date most activities of the OCA research group have concentrated on building the GIS sightings database and establishing a killer whale sighting network. Other research endeavours include a photoidentification database and acoustic monitoring. Current planning calls for dedicated field research in summer 2007, in Repulse Bay, to record and photograph killer whales and conduct focal follows.

Photographic identification

Long-term photoidentification studies (Black et al. 1997; Dahlheim 1997; Dahlheim et al. 1997; Ford and Ellis 1999; Matkin et al. 1999; Ford et al. 2000) have considerably advanced knowledge of killer whale ecology, population dynamics and social structure. The OCA team has started initial work on compiling photographs. To date all collected photographs were taken opportunistically and not during dedicated killer whale field work. Photographs are available from Baffin Bay, near Pond Inlet and near Churchill in summer 2004, Admiralty Inlet, Pond Inlet and Repulse Bay in August 2005 (both sightings on the same date), and near Rankin Inlet in August 2006. Only some of these photos are suitable for photoidentification studies (e.g., two adult males in Repulse Bay in August 2005, Figure 11). Dedicated field research will be required to collect quality identification photos. The two adult males in Figure 11 have been compared to a catalogue in development in Newfoundland (www.atlanticwhales.com) (also see Lawson and Snow 2007), with no matches.

Acoustic monitoring

Acoustic monitoring of killer whales started in summer 2006 in conjunction with a related project on beluga whale vocalizations. Two autonomous acoustic recorders (AURAL, Multi-electronique, Rimouski, Quebec) were deployed in Hudson Bay in 2006. The one near the Seal River in Manitoba was deployed from July 17 to August 12, 2006 and recorded 330 hours. The second AURAL was deployed August 9 to September 2, 2006 near Repulse Bay, and recorded 307 hours. Killer whales were observed in the Repulse Bay area while the recorder was deployed (J. Kringayark, pers. comm.). About one third of the recordings from Repulse Bay have been listened to and beluga, narwhal, and killer whale sounds have all been heard. Analyses of recordings are continuing (E. Chmelnitsky, pers. comm.). In summer 2007 six autonomous recorders will be deployed (Bellot Strait, Repulse Bay [2 AURALS], Pond Inlet, Rankin Inlet, and Seal River), and portable hydrophones will be used by field researchers. In 2008 one additional AURAL will be deployed near the Yukon-Alaska border as part of the International Polar Year (IPY) Circumpolar Flaw Lead project. Cooperating American scientists have also purchased a number of AURALs that are being put out in Alaskan waters and in Davis Strait.

NORTH ATLANTIC KILLER WHALES

Killer whales are also found throughout the Canadian North Atlantic (Sergeant and Fisher 1957; Katona et al. 1988; Lien et al. 1988; Mitchell and Reeves 1988; Reeves and Mitchell 1988a; Wenzel and Sears 1988). The most predictable occurrence of killer whales in the North Atlantic occurs in the Strait of Belle Isle region of northern Newfoundland and southern Labrador (D.

Snow, pers. comm.; Lawson and Snow 2007). The current version of the database excluded records for this region to concentrate on Arctic regions. Research on killer whales off Newfoundland and southern Labrador is currently being conducted by DFO and Wildland Tours, a local ecotourism company (Lawson and Snow 2007). Plans are underway to merge sighting databases for the Arctic and Atlantic regions (Newfoundland and Labrador, the Maritimes, and Quebec) (NSDMC Virtual Data Centre proposal).

CONCLUSIONS

While much is left to be learned, these analyses offer some improvement in knowledge on killer whales in the eastern Canadian Arctic. The highest numbers of sightings reports are from the southwest Greenland and Lancaster Sound ecoregions. Killer whale sightings are widely distributed throughout the study region but are clumped in several areas. "Hotspots" for killer whales in the eastern Arctic include Disko Bay, Cumberland Sound, Pond Inlet/Bylot Island, Lancaster Sound, Admiralty Inlet, and western Hudson Bay (particularly the Repulse Bay area). Regular occurrence of killer whales in Hudson Bay is a recent phenomenon and appears to be related to declining ice concentrations in Hudson Strait (Higdon et al. 2006; Higdon and Ferguson 2007).

Killer whales have been reported throughout the year, but nearly all records occur during the months of June to September (also see Lawson and Snow 2007). Stock structure is poorly known but there is little evidence for large-scale migration from Newfoundland to the Arctic. Whales are observed off Newfoundland and Labrador throughout the summer months, the same time that whales are reported at higher latitudes. This suggests that there are either several populations in eastern Canada, or one large, widely distributed population. Wintering locations are also unknown. Killer whales have been reported off both Newfoundland and Greenland during the winter (Heide-Jorgensen 1988; Lien et al. 1988), and Arctic whales may winter at one or both of these locations, or further offshore into the northwest Atlantic.

Killer whales in the Canadian Arctic prey on a variety of species. Nearly all records are of predation on marine mammals, including bowhead and fin whales, narwhal and beluga, and various seal species. There are also two records from Greenland of killer whales eating fish. It is currently unknown whether or not Arctic killer whales are segregated into ecotypes such as those found in the Pacific and Antarctic (Ford et al. 2000; Baird 2001; Pitman and Ensor 2003). Killer whale group size is highly variable, ranging from one to over 100 whales. Mean and median group size were 10 and three, respectively, with most records of 10 or less whales. There was no significant difference in group size between the different regions, although reported group sizes were generally larger in the Davis Strait-Baffin Bay and northwest Greenland ecoregions.

Killer whales are occasionally found stranded, and ice entrapments are another source of natural mortality. However the biggest mortality source is direct killing by humans. Killer whales have been sporadically killed by Canadian Inuit, total harvest levels are unknown however likely low. The harvest in West Greenland is considerably higher, especially in recent years when statistics indicate that a minimum of 55 killer whales were killed between 1996 and 2006. These values are likely underestimates due to struck and lost and non-reporting, and the sustainability of these harvest levels is completely unknown. However over-reporting is also a possibility that needs to be investigated. Determining population sizes and trends, and the impact of Greenland harvests on Canadian whales, are critical research priorities. The effect of contaminants on Arctic killer whales is another research priority.

The sightings database can be used to refine field research by determining the optimal time and locations to attempt surveys. Future research plans call for intensive field work to collect identification photographs and record vocalizations. In summer 2007 acoustic monitoring will again concentrate in Hudson Bay, but it will be expanded to other regions of the Canadian Arctic. Another research priority is a study of Inuit traditional knowledge on killer whales. In the past

there have been no dedicated surveys of Inuit knowledge on this species, although some information is available from studies on other cetacean species (Remnant and Thomas 1992; Stewart et al. 1994; Hay et al. 2000; Gonzalez 2001) and land-use studies (Brody 1976; Brice-Bennett 1977). Inuit hunters are the true Arctic killer whale experts and they have been reporting increased sightings throughout Nunavut. Collecting this knowledge will be a critical step towards improving knowledge on Arctic killer whales. A killer whale traditional knowledge questionnaire has been developed and is being tested in Repulse Bay in summer 2007 (K. Westdall, University of Manitoba). Another research priority will be expanding the sighting network already in place, where northern residents will again play a major role.

Recent (i.e., post-1988) sightings in the database are largely limited to Nunavut, and there are few recent records for Nunavik, northern Labrador, and West Greenland. Cooperation with other eastern Canadian DFO regions (i.e., Newfoundland and Labrador, Maritimes, and Quebec) is ongoing, but international cooperation with Greenland may be more critical. Establishing stock relationships of Arctic killer whales, including the possibility of movement between Canada and Greenland, is a research priority which may be best accomplished through NAMMCO. This will require dedicated genetic analyses of collected biopsy samples from eastern Canada and West Greenland.

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Table 1. Number of killer whale sighting reports per ecoregion. The first six ecoregions are found in the North Atlantic and are not included in this version of the killer whale sightings database (see Lawson and Snow 2007).

Ecoregion no.	Ecoregion name	No. killer whale reports
1	western Scotian Shelf - Gulf of Maine	NA (not applicable)
2	Gulf Stream	NA
3	Gulf of St. Lawrence - eastern Scotian Shelf	NA
4	southern Grand Banks - south Newfoundland	NA
5	northern Grand Banks - southern Labrador	NA
6	Labrador Sea south	NA
7	Labrador Sea north	10
8	northern Labrador	6
9	southern Baffin Island (northern Labrador Ecoregion)	61
10	Davis Strait-Baffin Bay	30
11	Lancaster Sound	80
12	northwest Greenland (Uummannaq District north)	51
13	southwest Greenland (Disko Bay south)	148
14	Hudson Strait	20
15	Foxe Basin	8
16	Hudson Bay	50
17	eastern Hudson Bay - James Bay	2
18	Arctic Basin	0
19	High Arctic Archipelago	1
20	Viscount Melville	0
21	Beaufort Sea-Amunsden Gulf	18
22	Queen Maude Gulf	0
	unknown	4
Total		485

Table 2. Number of killer whale records over time for the eight ecoregions with the most sighting reports (n = 428).

Time period	Ecoregion							
	9 - southern BI	10 - DS-BB	11 – L. Sound	12 - NW Greenland	13 – SW Greenland	14 – H. Strait	15 – F. Basin	16 – H. Bay
1750s					2			
1800-1849					9			
1850-1899	12	9	11	2	10	1		
1900s		2	2		2	1		
1910s	1		2			1		
1920s		1	8		2	1		
1930s	1		3	2	1	2	1	
1940s			11	2	6	2	1	2
1950s	7		8	5	6		1	
1960s	14	1	7	3	23	3	1	2
1970s	14	1	6	18	20	1		1
1980s	3	3	5	10	63	2		6
1990s	1	3				3	1	6
2000s	4	9	16	1	2	3	2	30

Table 3. Seasonal distribution of killer whale sightings for six areas in the eastern Arctic with relatively regular and predictable occurrences of killer whales.

Month	Region					
	Pond Inlet area	Admiralty Inlet	Lancaster Sound	Cumberland Sound	northwest Hudson Bay	Disko Bay
January						1
February						1
March						
April						1
May						2
June	1					3
July	12				7	8
August	12	11	4	15	6	1
September	8	1	3	6	1	8
October	1	1	2	1		6
November						1
December						1
spring	1			2		
summer	3	1		8	4	
fall	1			2		
Total	39	14	9	34	18	33

Table 4. Descriptive statistics for killer whale group size, for all records combined and by region (see Table 1 for ecoregion names).

	Ecoregion										
	all regions	7	8	9	10	11	12	13	14	15	16
Mean	10	7	2	6	17	7	19	10	3	4	9
Std. error	1.21	2.37	0.48	1.24	8.29	1.47	5.98	1.73	0.62	1.50	3.76
Median	3	4	2	4	2	4	8	3	2	2	5
Mode	1	2	1	1	2	1	1	1	1	1	1
Std. deviation	20.07	6.71	0.96	6.22	28.72	7.78	36.36	18.27	2.32	3.98	19.18
25th percentile	1	2	1	2	2	2	3	1	1	2	1
50th percentile	3	4	2	4	2	4	8	3	2	2	5
75th percentile	10	13	2	10	23	10	15	10	4	5	9
90th percentile	20	16	3	14	34	16	38	30	6	8	15
Sample size	277	8	4	25	12	28	37	111	14	7	26

Table 5. Known harvests of killer whales in the eastern Canadian Arctic and West Greenland since 1950. Values in parentheses are "unconfirmed" word of mouth reports with no available evidence to support accuracy (further details on sources in text). "Natural" mortality is not included (see discussion in text).

Year(s)	Eastern Canadian Arctic	West Greenland
1950s		5
1956 or 1959	2 (12)[1]	
1960-1986		70[2]
1967	(6)	
1969	4	
1977	14	
1978	1	
1981	(12)[3]	
1995	(1)	
"recently"	(5-6)	
1996-2006		55 (75)[4]
Total	21 (36-37)	130 (150)

[1] Reeves and Mitchell (1988b) reported that 2 whales, trapped in ice, were killed by hunters in Foxe Basin. However local elders report that 12 whales were trapped, two were retrieved but all were likely killed (see text)

[2] Official Greenland harvest statistics from 1960 to 1984 indicate 22 whales, however research by Heide-Jorgensen (1988) indicated a minimum of 70 whales from 1960 to 1986 when unreported and struck and lost whales were added.

[3] This account of 12 whales killed in Cumberland Sound may represent confusion with the confirmed report of 14 whales killed in 1977 (Reeves and Mitchell 1988b)

[4] Official Greenland hunting statistics reported in Piniarneq (2005, 2006) noted 153 whales between 1999 and 2004. Subsequent checking and verification by the Greenland Institute of Natural Resources (GINR) has reduced this number substantially. The 55 whales reported here excludes four whales taken in East Greenland (2003-2004). During the period December 2001 to February 2002 GINR staff verified a total harvest of 20 whales. External sources (ACS 2002; George 2002) indicated a total harvest of 40 whales during this event, and the same number was suggested by a hunter interviewed by the GINR (F. Ugarte, GINR, pers. comm.).

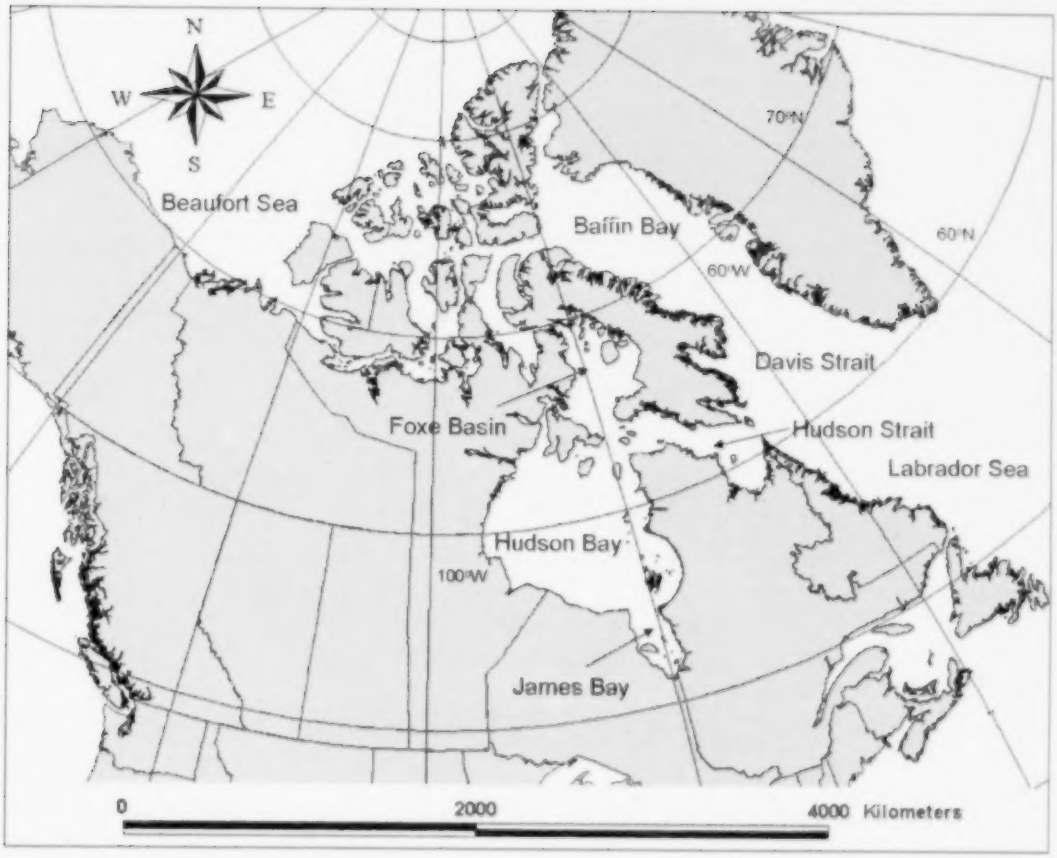
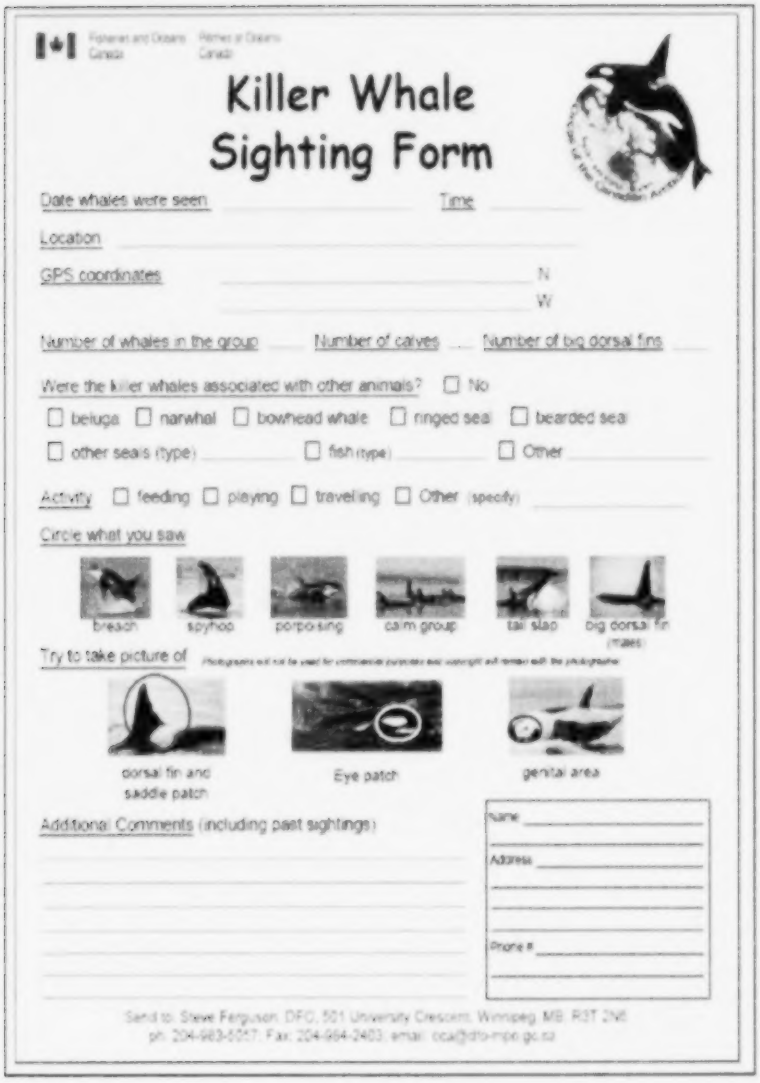


Figure 1. Map of the Canadian Arctic showing major water bodies.



Fisheries and Oceans Canada / Pêches et Océans Canada

Killer Whale Sighting Form

Date whales were seen _____ Time _____

Location _____

GPS coordinates _____ N

_____ W

Number of whales in the group ____ Number of calves ____ Number of big dorsal fins ____

Were the killer whales associated with other animals? ☐ No

☐ beluga ☐ narwhal ☐ bowhead whale ☐ ringed seal ☐ bearded seal

☐ other seals (type) _____ ☐ fish (type) _____ ☐ Other _____

Activity ☐ feeding ☐ playing ☐ travelling ☐ Other (specify) _____

Circle what you saw

breach spyhop porpoising calm group tail slap big dorsal fin (male)

Try to take picture of

dorsal fin and saddle patch

Eye patch

genital area

Additional Comments (including past sightings)

Name _____

Address _____

Phone # _____

Send to: Steve Ferguson, DFO, 501 University Crescent, Winnipeg, MB R3T 2N6
ph: 204-983-5017, Fax: 204-984-2403, email: ccs@dfo-mpo.gc.ca

Figure 2. Killer whale sighting form (also in Inuktitut) developed and distributed throughout Nunavut.

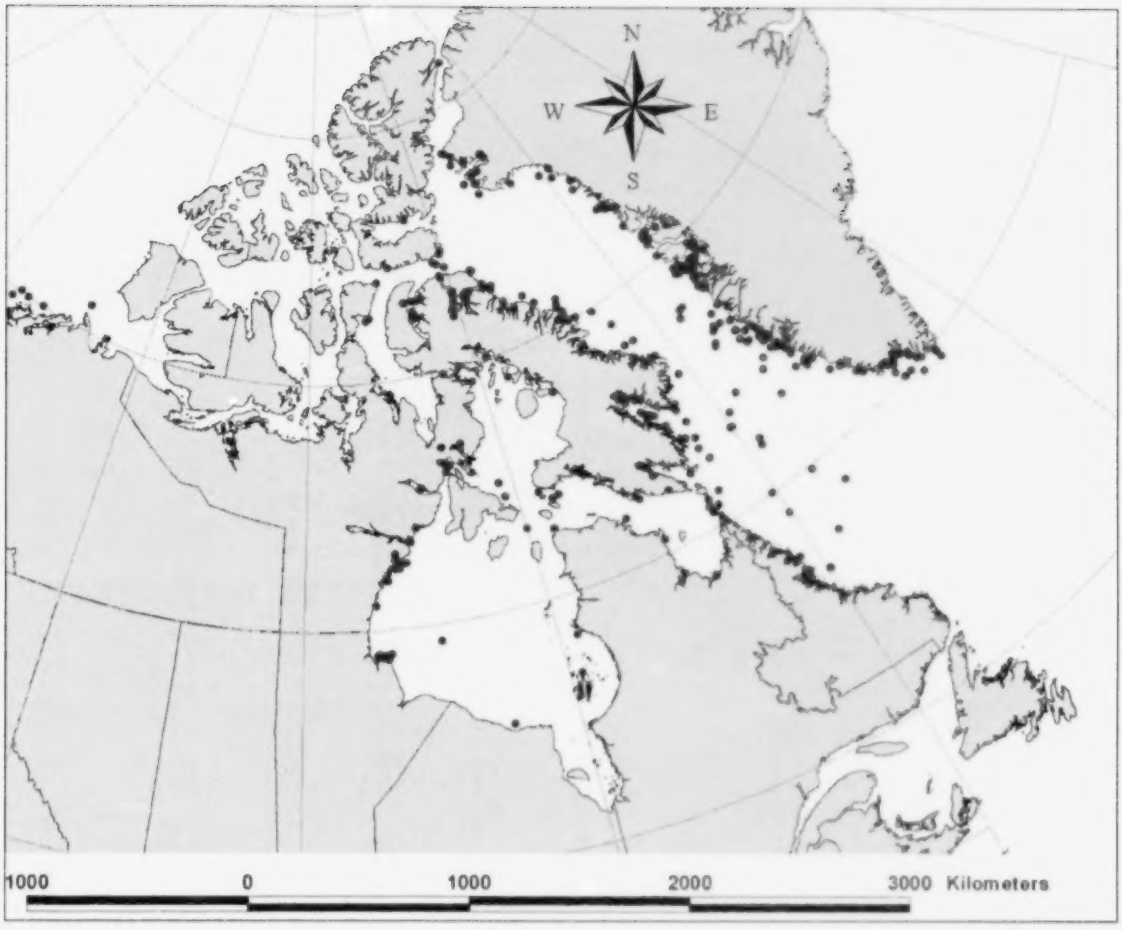


Figure 3. Distribution of the 485 Arctic killer whale sighting records in the Orcas in the Canadian Arctic (OCA) database. Location accuracy varies considerably among reports, and many represent approximate locations only.

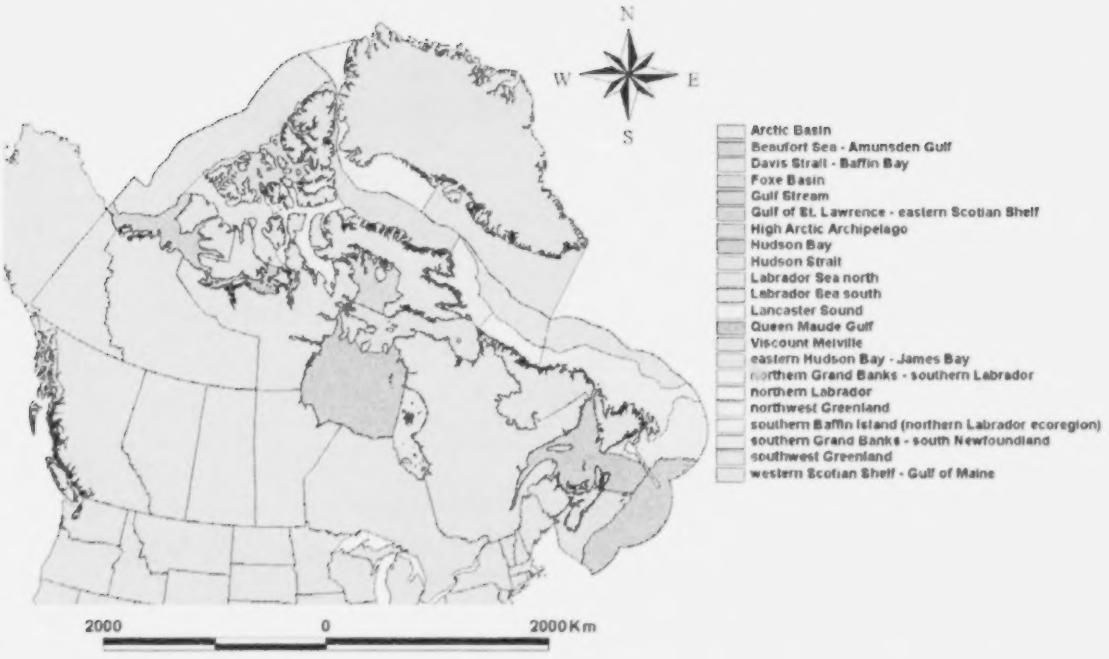


Figure 4. Ecoregions used to characterize spatial distribution of killer whale sightings (modified from Powles et al. 2004 and Stewart and Lockhart 2005).

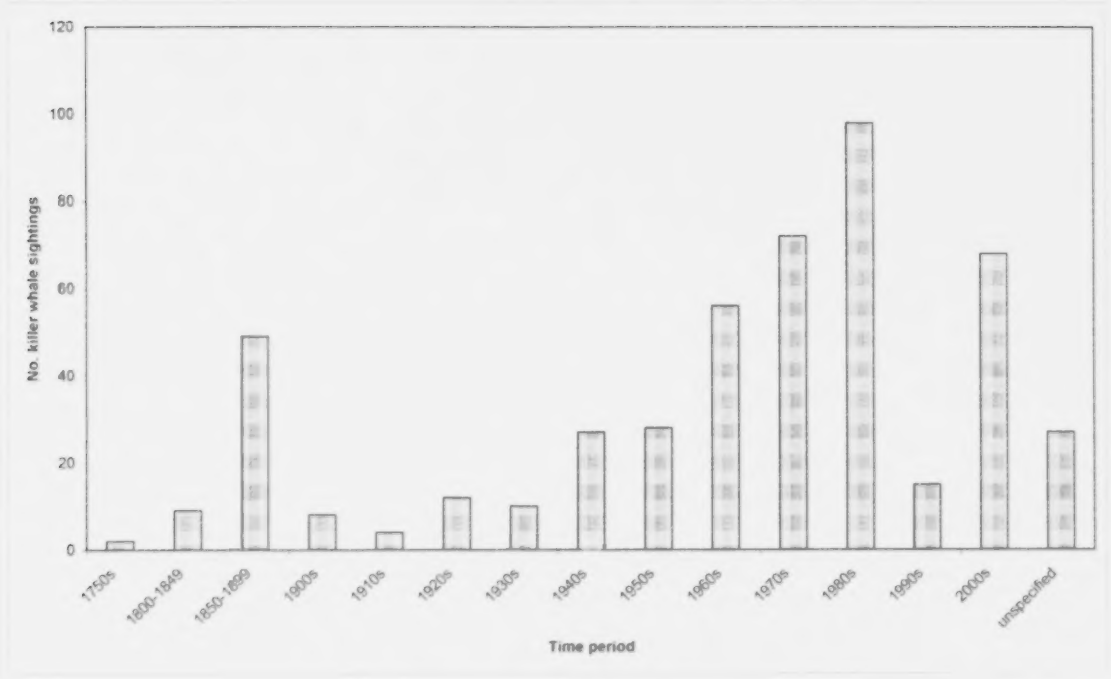


Figure 5. Number of database records over time.

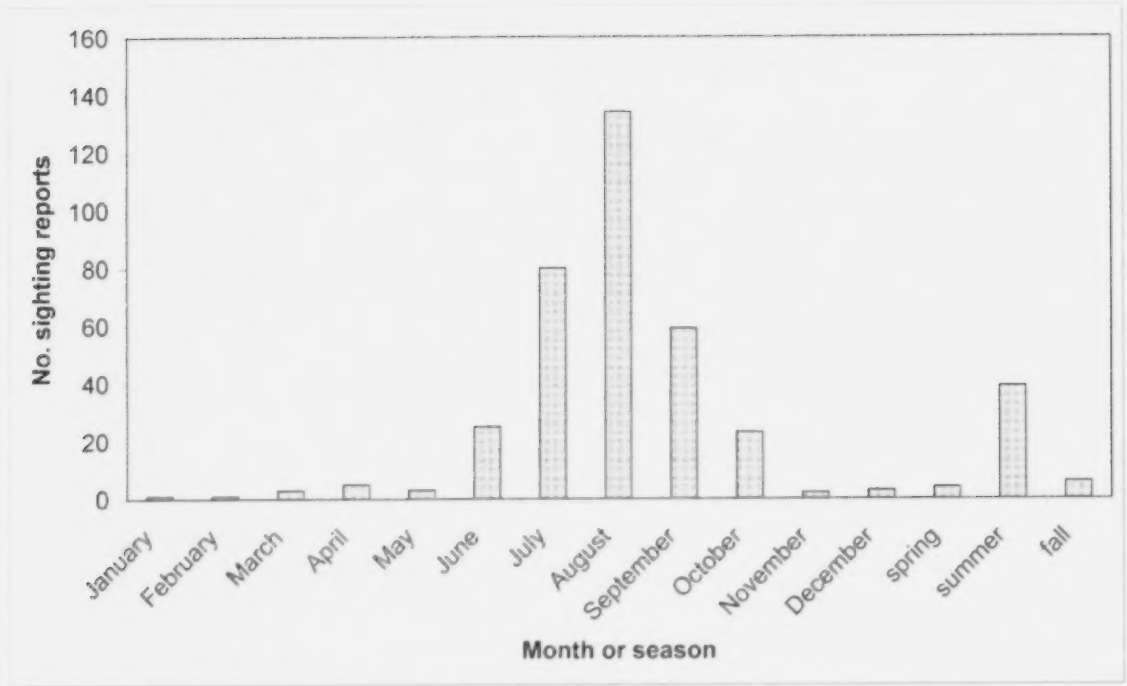


Figure 6. Month (or season) of sightings of killer whales. Not all database records included this information, sample size = 387.

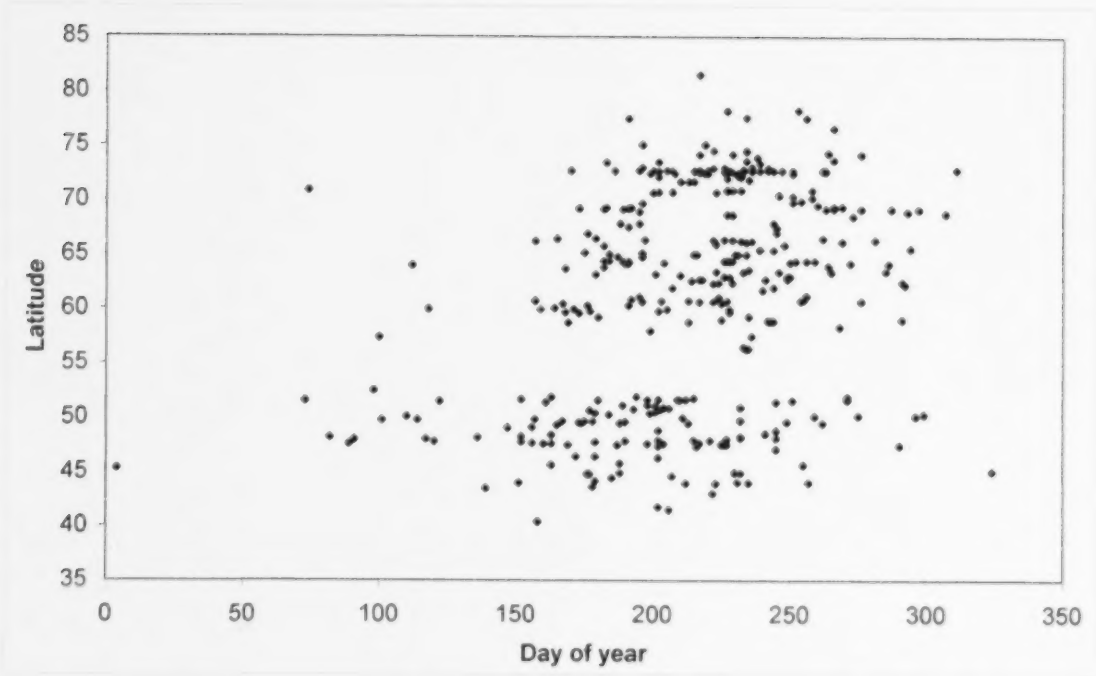


Figure 7. Scatterplot of day of sighting versus latitude for 374 killer whale sighting reports.

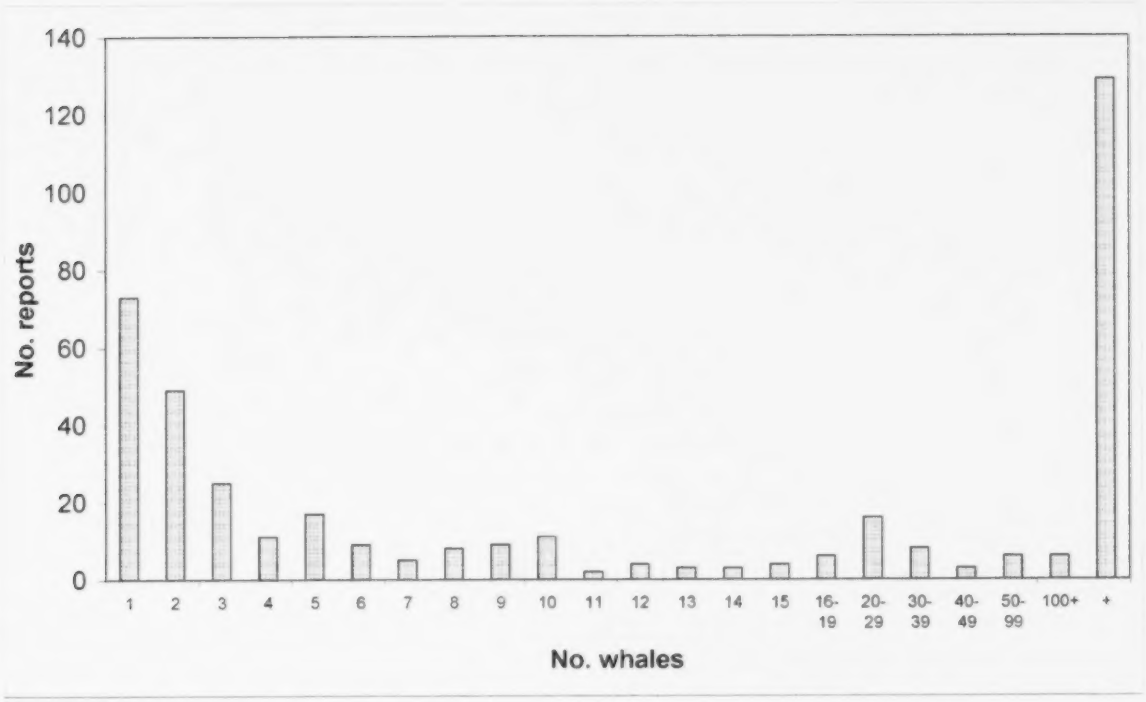


Figure 8. Numbers of killer whales reported from 407 records that include at least a qualitative description of the number observed. "+" indicates qualitative estimates that were greater than one whale, but actual numbers not given. Minimum value used for records with estimated range of two (e.g., 2-3, 5-6, etc.), and median values used for records with estimated range > two (3-5, 8-10, etc.).

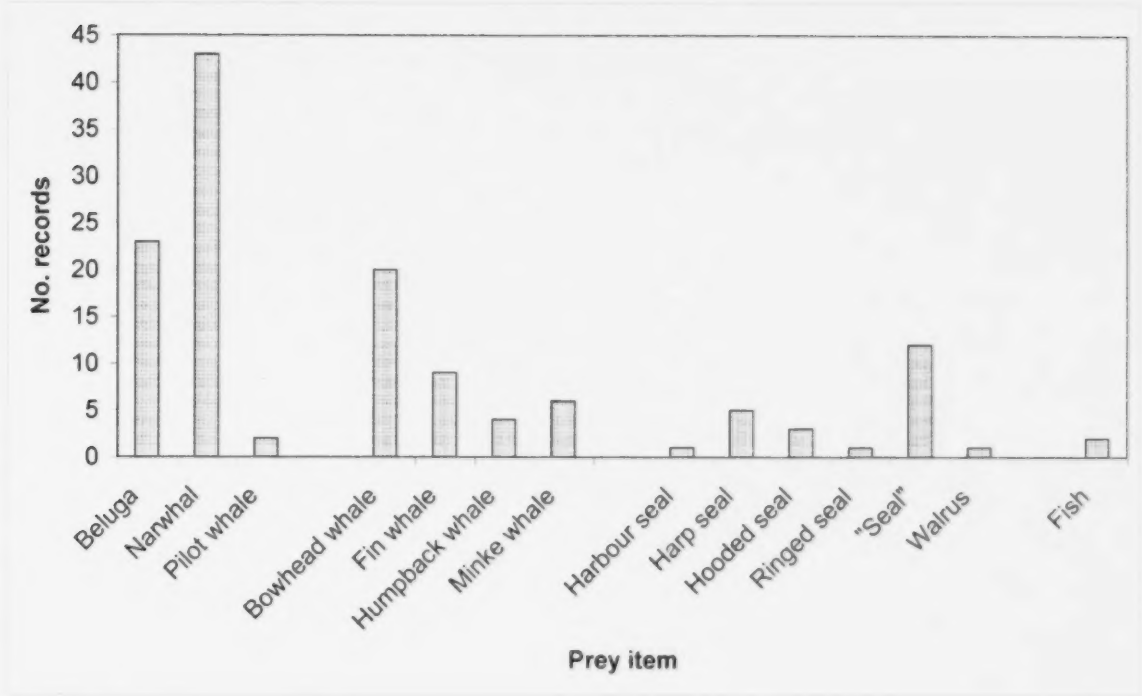


Figure 9. Distribution of prey species amongst 132 attempted or successful predation events. Predation noted in 123 records, with multiple prey species noted for several. The graph excludes two reports of predation on a "whale", one on a "baleen whale" and one on an unknown prey item.

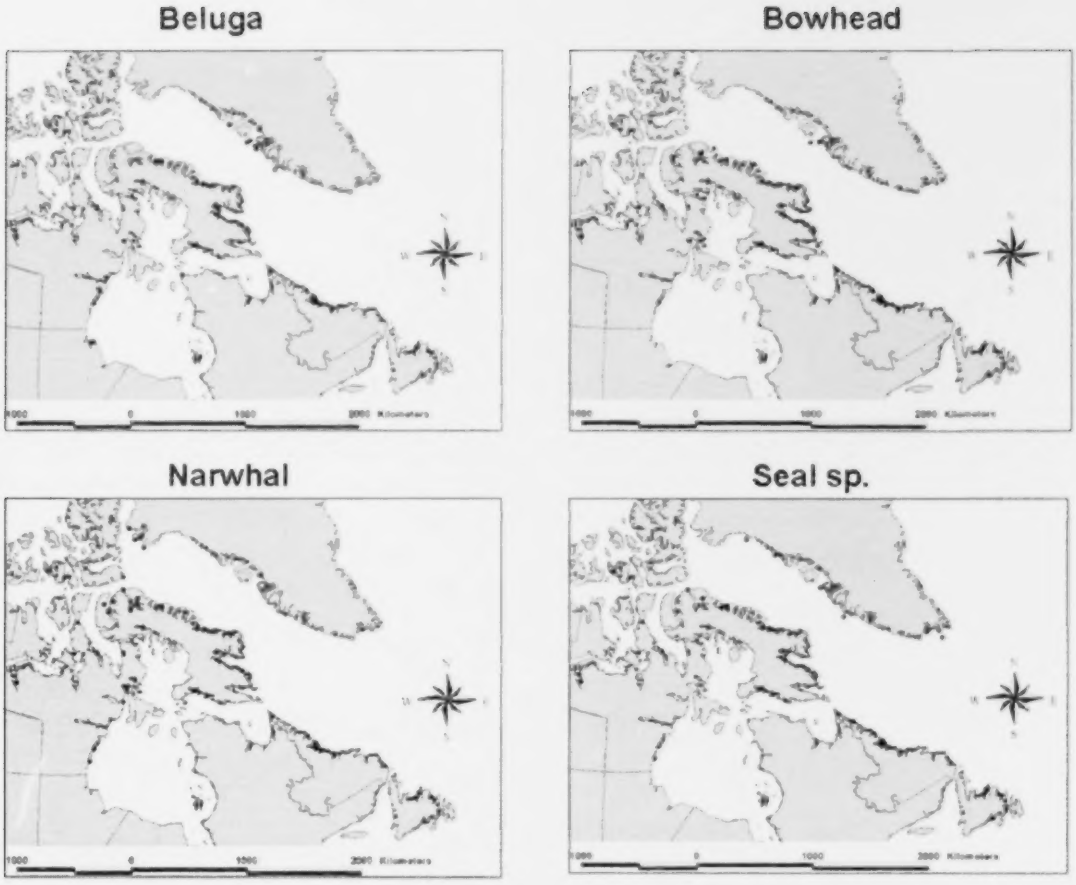


Figure 10. Distribution of recorded killer whale predation events on narwhal (n = 43), bowhead (n = 20), beluga (n = 23, one predation record for the Beaufort Sea not shown), and seal species (n = 22, excludes one report of unsuccessful predation on walrus in West Greenland).

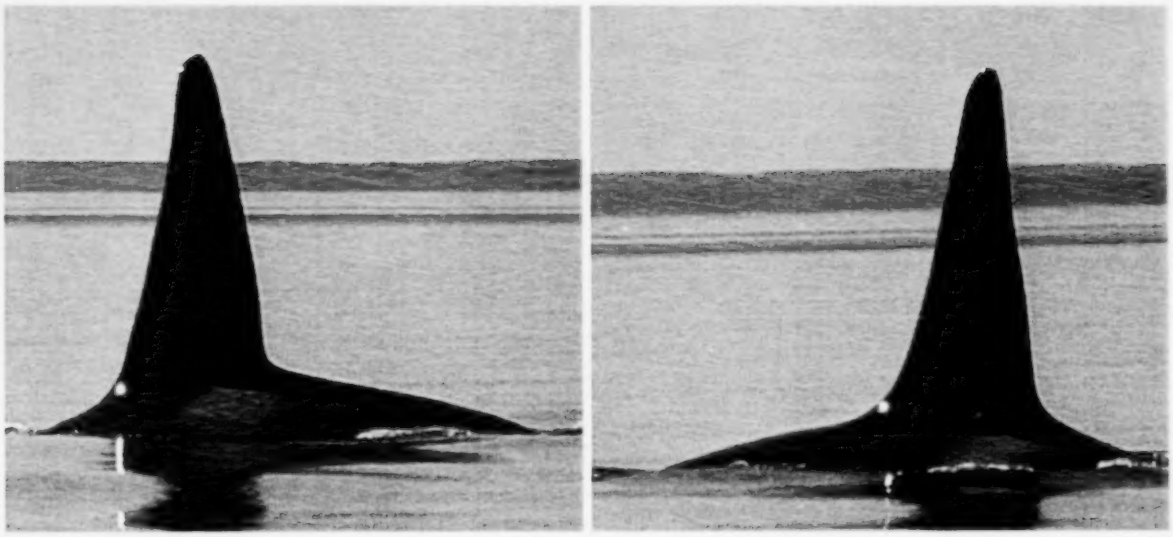


Figure 11. Photographs of two adult male killer whales taken near Repulse Bay, in northwest Hudson Bay, in August 2005. Photographs by B. Guptill – Fisheries and Oceans Canada.